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THE NEW FLORA OF KRAKATAU

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IN August, 1883, there occurred in the Straits of Sunda, between Java and Sumatra, the most violent volcanic eruption of which there is any record. This catastrophe involved the island of Krakatau (Krakatoa, as it is usually written in English), as well as the two small neighboring islands, Verlaten and Lang Island. As a result of this eruption about two thirds of the larger island, which was nine kilometers long and five in width, disappeared, while the other islands were noticeably increased in size, and the whole floor of the ocean in the vicinity was completely changed. It was estimated that the total amount of matter ejected during the successive eruptions from May to August amounted to eighteen cubic kilometers, and this immense mass of stones, ashes and volcanic dust was scattered over an enormous area, the ashes being carried many hundred miles, and life of all kinds upon the islands was completely annihilated. Many will recall the brilliant crimson sunset skies that were observed all over the world some months later. These were caused by the presence of fine volcanic dust from Krakatau which, suspended in the upper atmosphere, was carried entirely around the world. The detonations from the explosions were said to have been heard nearly three thousand miles away; and at Buiten-

zorg and Batavia, in Java, about 150 kilometers away, the explosions were likened to the discharge of cannon near at hand, and were so violent as to shake the houses to such an extent that objects were thrown down.

The effect of the great mass of hot ashes and pumice that completely covered the islands, was to entirely destroy every vestige of the luxuriant vegetation which before the eruption clothed the island of Krakatau with a dense forest extending from the shore to the summit of the highest peak, *Rakata*, 832 meters in height.

The island of Krakatau, therefore, after the eruption, was very efficiently sterilized, and offered a most unusual opportunity for studying the establishment of the vegetation upon a large area absolutely barren and comparatively isolated. The nearest land is an island some nineteen kilometers distant on which the vegetation was also largely destroyed, while the large islands of Java and Sumatra are respectively 35 and 45 kilometers distant.

Fortunately there was a man who fully appreciated the importance of this unique opportunity, and determined to trace the reestablishment of the new flora upon the desolated island. The botanical world owes a great debt to Professor Treub, the distinguished botanist who has done so much to advance the study of botany in the tropics, both by his own important investigations and by the building up of the unrivaled facilities for research offered by the magnificent gardens and experiment stations in Java.

Treub's visit was made in 1886, three years after the eruption, and subsequently the island was again visited by him in 1897, and a third expedition was made in 1905.

In the spring of 1906, while engaged in botanical study at the mountain station Tjibodas, in Java, I received word that a visit to Krakatau was being arranged for, and was invited to join it. The results of this trip have been presented in admirable fashion by Professor A.

Ernst,¹ of the University of Zürich, to whose efforts and energy the successful results of this trip were largely due. Considering the very brief time at our disposal, the amount of material secured by Professor Ernst and the completeness with which it was worked out were really remarkable.

On the morning of April 24 our little party set sail from Tandjong Priok, the harbor of Batavia, for our brief cruise among the islands of the Straits of Sunda, for Krakatau. The little coasting steamer "Snip" (Snipe), which had been placed at our disposal for the trip, proved most comfortable, and her captain did everything possible to make our trip a pleasant one. The party included, besides Professor Ernst, Mr. C. A. Backer, of the Buitenzorg Gardens, whose intimate acquaintance with the Malaysian flora was very much appreciated, and Dr. A. A. Pulle, of the University of Utrecht, who, like myself, was working at Buitenzorg. The weather proved all that could be asked, and the voyage over the calm, dazzling blue sea among the picturesque islands was one long to be remembered. As we sailed out of the harbor we could see in the distance the great volcanoes Salak and Gedeh, which dominate Buitenzorg, and which had become quite like old friends. On the slopes of Gedeh lies the mountain station Tjibodas, where I had spent several happy weeks, and to which I was going back on my return from Krakatau. Opportunity was given us to stop at several points *en route*, one being Vlakke Hoek, the southernmost point of the westerly peninsula of Sumatra. All of the places where we stopped showed a most interesting strand flora, including many striking plants, some of which we encountered again on the shores of Krakatau. The shallow lagoons within the coral reefs of these islands were full of interesting things, corals, sea anemones, gorgeously

¹ The New Flora of the Volcanic Island of Krakatau.' By A. Ernst, Ph.D., professor of botany in the University of Zürich. Translated by A. C. Seward, F.R.S., professor of botany in the University of Cambridge. Cambridge, at the University Press, 1908.

colored fish and many interesting algæ. Professor Ernst collected a large number of striking siphonous algæ which abound among the coral reefs. (For a list of the plants collected at these intermediate stations, see Professor Ernst's Memoir, pages 9 to 18.)

Vlakke Hoek was devastated by the great waves resulting from the eruption of Krakatau, the waves reaching a depth of fifteen meters and sweeping away practically everything except the great iron light house tower, which alone remains of buildings existing before the eruption.

From Vlakke Hoek we crossed the Straits of Sunda to the southwest coast of Java (Java's first point), and *en route* had our first view of the peak of Krakatau rising above the clouds to the east. The bold shores of the Javanese coast presented a great contrast to the flat, monotonous shore at Vlakke Hoek in Sumatra. The difference in the topography of the land is reflected in the plants, which were strikingly different from those of Vlakke Hoek (see Ernst, pages 24 to 26). Early in the morning of April 26, we approached the Krakatau group of islands.

The view of the island of Krakatau from the north is most impressive. During the great eruption the volcanic peak Rakata was cleft down the middle, so that from peak to base its northern side presents a perpendicular cliff half a mile high, falling sheer into the sea, which at the foot of the cliff is now more than three hundred meters deep. The exposed face of the cliff forms a perfect median section of the cone, and the arrangement of the rocks of which it is built up offers a most extraordinary picture. Professor Ernst took some admirable photographs, which are reproduced in Plate III of his Memoir.

At six o'clock we dropped anchor and soon after were taken ashore in one of the ship's boats. The landing was made on the east side of the island where the outer part of the beach forms a broad zone of mingled punice, coral and all sorts of débris; fragments of driftwood, seaweed

and a conglomeration of seeds and fruits washed up by the tide. Many of the fruits washed upon the shore were those of characteristic strand plants like cocoanuts, screw pines, Nipa palms and others. Most of these show various devices for facilitating their transport by water, and some of them had germinated and were trying to get a foothold in the loose mass of pumice and coral sand.

Above this outer drift zone there is a characteristic sandy belt where various typical strand plants have established themselves. The long prostrate stems of *Ipomœa pes-capræ*, that most ubiquitous of tropical strand plants, sprawled over the sand, and with these were masses of the curious grass, *Spinifex*, and a yellow flowered leguminous plant *Vigna lutea*, a euphorbia with thick, waxy leaves, and various other species common to the outer littoral zone of the Indo-malaysian region. While fruits of the Nipa palm were found, the plant has not yet got a foothold in Krakatau, and there is as yet no mangrove formation established.

Back of the beach a thrifty belt of forest is conspicuous and could be plainly seen long before we reached the island. Some of the trees in this forest are at least fifty feet high, the tallest being specimens of the curious *Casuarina equisetifolia* Forst., a genus mainly confined to the Australasian region, but with a few species widely distributed throughout the Malayan Archipelago. Associated with these were found specimens of screw pines (*Pandanus* sp.), and the striking *Terminalia Catappa* L., whose whorled branches and great shining leaves make it one of the most notable of tropical trees. Perhaps the most beautiful of all the trees of this strand forest is *Barringtonia speciosa* Forst., a tree with large, glossy, dark green leaves and great white flowers with a crown of stamens looking like an enormous myrtle flower. The curious four-sided angular fruits of this tree are very common along the beach. Of the few climbing plants the most conspicuous was *Vitis trifolia* L.

After spending some time exploring the beach and

strand forest, we pushed inland toward the south, not without much exertion and perspiration. The unclouded rays of an equatorial sun beat down pitilessly upon us, and when, after struggling over blocks of pumice and through thickets of tall grasses and bushes, we finally reached a small grove of cocoanut palms, full of fruit, we threw ourselves down on the ground under their grateful shade and took a well-earned rest. No time was lost in sending one of the natives up into a tree for green nuts, which were thrown down and quickly opened, and never did anything taste better than the cool, sparkling cocoanut water after our exhausting march through the fierce heat of the jungle.

From the ship we had seen that the ravines on the flank of the Rakata were filled with a dense growth of trees, forming the beginning of a new forest, but it was quite impossible to guess what the trees were. We tried to cross the open tract lying between the belt of forest on the shore and the cone in the center of the island, but we had to give up the attempt after penetrating some distance inland, following the dry bed of a stream for part of the way. The land was terribly rough and covered in many places with a dense jungle of grasses ten or fifteen feet high, through which he had to hew a path with the wicked-looking cutlasses which every Malay carries when traveling. The way lay over steep ridges, which grew worse and worse as we approached the cone, and finally we realized that with the short time at our disposal, and the limited means of cutting our way through the jungle and scrub, we should have to give up the attempt, which we did very reluctantly, and retraced our steps to the shore, where we embarked for the ship.

The monotony of the journey over the grass steppes in the interior of the island was broken by encounters with countless ants which built their nests everywhere, in the crevices of the rocks, among the roots of the grasses and shrubs, and even hanging from the branches of the shrubs and trees; and as we scrambled up the steep slopes

of the frequent small ravines, down would come showers of ants, swarming all over us but not doing any serious damage. Few showy flowers were seen, the most striking being several terrestrial orchids, one of which *Arundina speciosa* Bl. was quite common and decidedly handsome.

After boarding the ship, we sat sail for the north side of the island, where a landing was made at the base of the rock wall formed by the fractured face of the riven cone of Rakata. As we approached the face of the cliff, we were startled to see what looked like puffs of smoke rising from various fissures in the cliff. Remembering the history of the mountain, and also having just received the news of the eruption of Vesuvius and the terrible earthquake at home, the thought occurred that perhaps Krakatau was getting ready for another outburst, which to say the least, was not reassuring. But we finally discovered that the "smoke" was merely clouds of dust caused by the falling of *débris* from the face of the cliff.

Our landing was made in a broad bay where there is a narrow beach, but the development of the strand flora is much less advanced than on the south side of the island. Ferns were noticeably abundant, as they were on the other parts of the island when it was first visited after the eruption. *Nephrolepis exaltata* Schott was especially frequent, and in the crevices in the rocks we found numerous prothallia and young plants of a species of *Gymnogramme* and of several other ferns. Some of the ferns and other plants which were growing upon the ground here are usually epiphytes. Of these *Polypodium quercifolium* L. was the most conspicuous.

After exploring the interior and strip of land at the base of the cone, we returned to the ship. Before the sun went down we set sail for Java and soon the peak of Krakatau was left behind us. The next morning found us safely back in Tandjong Priok.

THE REESTABLISHMENT OF THE FLORA ON KRAKATAU

When the island was first visited by a geological expedition two months after the eruption, the whole surface was buried under a layer of ashes and pumice averaging thirty meters in depth, and in some places as much as sixty meters. Thus, of course, every trace of life must have been quite annihilated and the sterilization was complete. An analysis of the ashes showed that, except for phosphorus and nitrogen, all of the elements necessary for plant life were present. (See Ernst, p. 50.) Ernst suggests that the other elements necessary for the establishment of a new flora were conveyed from the mainland in the form of dust, and that as a result of the intense electrical activity which accompanies the almost daily rains of the equatorial region, the atmospheric nitrogen is oxidized into the nitric and nitrous acids which furnish the necessary nitrogen. This with the salts and traces of organic matter in the ashes would have been sufficient in a very short time to allow the establishment of the first micro-organisms upon the island.

The first botanical expedition, as already stated, was made under the direction of Professor Treub in 1886, three years after the eruption. During this interval a considerable number of plants had already established themselves upon the island. The most important fact brought out by this trip was the great importance of the blue-green algæ in the early establishment of the new vegetation. Thin blackish, slimy films, formed by a number of species of *Oscillatoria* and other blue-green forms, were found in great quantity coating the surface of the ashes, and the gelatinous matrix of these low plants offered a substratum which was favorable for the germination of the spores of ferns and even for the seeds of a few phanerogams. It was found that the colonization of the island was quite as marked in the interior and upon the high cone as it was along the shore, but the plants of the interior of the island were for the most part

quite different. A remarkable fact was the great preponderance of ferns in the new flora. In the period of three years no less than eleven species had established themselves and formed the predominant feature of the new vegetation. In our visit to the north side of the island, where the reestablishment of the vegetation, as we have seen, was less advanced than on the south side, this preponderance of ferns was very marked, whereas in the other parts of the island they have been to a very great part supplanted by the phanogamous immigrants and several species seem to have disappeared. In the drift zone of the beach Treub found nine species of seedling plants, and in the central part of the island eight, two of which were the same as those upon the shore. Of the remaining six, four were composites and two grasses, all forms which would be distributed readily by the wind. These phanerogams, however, were far less numerous as individuals than were the ferns.

A series of visits to the islands was projected by Treub, but unfortunately the plan could not be carried out, and it was not until 1897 that a second expedition visited Krakatau. This second expedition was also under Treub's direction. In the interval of more than ten years that had elapsed since the first visit the number of plants had greatly increased and most of the island was covered with vegetation which began to show the characteristic formations which are now so conspicuous. The "*Pescapra*" formation, *i. e.*, the beach zone characterized by the predominance of *Ipomæa pes-caprae*, was well established, but the belt of strand forest now so marked upon the southern side of the island was entirely wanting in Krakatau, but the beginning of such a forest was found upon the neighboring Verlaten Island. Almost no trees were met with, and even shrubby plants were not numerous. The grassy "steppe" lying between the beach and the base of the cone was conspicuous and probably not very different from its present condition. The total number of vascular plants collected on this second ex-

pedition amounted to sixty-two, of which twelve were pteridophytes and fifty phanerogams. The ferns still predominated in number of individuals.

A third party visited the island in 1905, but the results of this expedition have not yet been published.

A very full account of the present flora is given by Ernst (pp. 37 to 48). In the three expeditions the results of which have been published a total of 137 species is recorded. While a very large majority of these are phanerogams, representatives of all the principal groups of plants have been collected. In the earlier expeditions the preponderance of ferns, as we have seen, was very noticeable, but at present this is not the case and they have largely given place to the more aggressive phanerogams. We collected only six species of ferns and one of *Lycopodium*, the wide spread *L. cernuum*, while on the first and second expeditions eleven species were noted, and although it is true that we failed to reach the center of the island, where in all probability other species would have been encountered, it may be noted that we collected seventy-three species of phanerogams against forty-eight species recorded at the time of the second expedition.

Of the lower plants only two species of mosses have been collected and a single species of antheroceros (this was found only on the second expedition). We found the two species of mosses growing fairly abundantly, but no liverworts. Whether the latter grow in the central part of the island remains to be seen, but it is highly probable that some of the very numerous species of Java and Sumatra will be found there. The scarcity of bryophytes is remarkable, as it is generally assumed that their spores are readily disseminated; and the contrast with the ferns which so quickly colonized the island is most striking. Three species of fleshy fungi have been collected and a considerable number of species of diatoms and blue-green algæ were among the earliest settlers of the island.

Professor Ernst made some interesting studies on the

bacteria, collecting from several places samples of soil which were placed in sterilized tubes. These were examined by Dr. E. De Kruyff, bacteriologist of the Agricultural Department at Buitenzorg, and the soil was found to contain the usual proportion of bacterial forms, both ordinary soil bacteria and putrefactive types. An interesting discovery was the presence of a new aerobic nitrogen-fixing bacterium, which was named *Bacterium krakatauï*. *B. radicicola* is present in abundance in the root tubercles of the numerous leguminous plants which now abound on the island. It is evident that the different kinds of bacteria must have very early established a foothold upon the sterilized island surface and were no doubt among the factors which rendered the establishment of the higher types of vegetation possible.

A most interesting find was a single thrifty female specimen of *Cycas circinalis*. This tree had a trunk nearly two meters in height, and the size of the plant suggested that it was a survivor of the original flora; but Ernst states that this is impossible, as the portion of the island where it is growing belongs to the new shore formed since the eruption.

AGENTS IN DISTRIBUTION

Ernst has treated very fully the question of the agents by which most of the members of the new flora were introduced (pages 53 to 68). There seems no doubt that the earliest immigrants—bacteria, blue-green algæ, ferns and mosses, were wind borne, and the same is probably true of the first phanerogams found upon the island, composites and grasses, but other agents have been active in transporting seeds and fruits to the shore of the devastated island, and of these the ocean currents have probably been most important. There is no question that the fruits and seeds of the strand plants are probably all water borne, and Ernst called attention to the important part played by driftwood in introducing new plants whose seeds might have been lodged in the crevices in the

bark, or he even suggests the possibility of young plants being transported on uprooted trees. The shore of the island is covered with masses of logs and fragments of trees which might very well have brought with them not only vegetable immigrants, but animals as well. An interesting case was that of the two species of fleshy fungi, *Polystictus*, which were found growing upon logs lying on the shore, and whose mycelium almost certainly had been growing in the logs before they were drifted out to sea.

Birds have undoubtedly also played their part in the introduction of seeds, especially those of fleshy fruits such as the species of *Vitis*, common near the shore, and several species of figs found somewhat further inland.

The rapid development of the vegetation in the nine years between the visit to the island in 1897 and our visit in 1906, and especially the great increase in the forest vegetation, makes it evident that before very long the forest which originally covered the island will be again in possession. Already the belt of forest along the shore is working inland, and it is to be expected that the patches of forest in the ravines flanking the cone in the interior of the island are spreading shoreward, so that in the course of time the intermediate belt of grassy land will probably be completely obliterated and the forest will once more be in undisputed possession of the entire island.